

# **IEEE Recommended Practice for Space Charge Measurements on High- Voltage Direct-Current Extruded Cables for Rated Voltages up to 550 kV**

IEEE Dielectrics and Electrical Insulation Society

Sponsored by the  
Standards Committee

# **IEEE Recommended Practice for Space Charge Measurements on High- Voltage Direct-Current Extruded Cables for Rated Voltages up to 550 kV**

Sponsor

**Standards Committee**  
of the  
**IEEE Dielectrics and Electrical Insulation Society**

Approved 23 March 2017

**IEEE-SA Standards Board**

**Abstract:** The aim of this recommended practice is establishing a protocol for the measurement of space charges in high-voltage direct-current (HVDC) extruded cables having rated voltage up to 550 kV. Such measurements are prescribed to be carried out at the beginning and at the end of load cycle qualification tests (either the long-duration voltage test of prequalification tests or the load cycle test of type tests). The various steps of the protocol for the measurement of space charges in such cables are carefully described. Details are given about the procedure for applying and switching off the voltage, the preparation and conditioning of specimens, the measurement times during poling and depolarization, and the calculations for checking electric field stabilization. The ultimate goal of this recommended practice is not verifying the compliance with any maximum acceptable limit of either space charge or electric field, but rather assessing the variation of the electric field profile in the cable insulation wall during load cycle qualification tests.

**Keywords:** HVDC extruded insulation, IEEE 1732™, power cables, power cable testing, space charge measurements

---

The Institute of Electrical and Electronics Engineers, Inc.  
3 Park Avenue, New York, NY 10016-5997, USA

Copyright © 2017 by The Institute of Electrical and Electronics Engineers, Inc.  
All rights reserved. Published 30 June 2017. Printed in the United States of America.

IEEE is a registered trademark in the U.S. Patent & Trademark Office, owned by The Institute of Electrical and Electronics Engineers, Incorporated.

PDF: ISBN 978-1-5044-3917-6      STD22512  
Print: ISBN 978-1-5044-3918-3      STDPD22512

*IEEE prohibits discrimination, harassment, and bullying.*

*For more information, visit <http://www.ieee.org/web/aboutus/whatis/policies/p9-26.html>.*

*No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.*

## **Important Notices and Disclaimers Concerning IEEE Standards Documents**

IEEE documents are made available for use subject to important notices and legal disclaimers. These notices and disclaimers, or a reference to this page, appear in all standards and may be found under the heading “Important Notices and Disclaimers Concerning IEEE Standards Documents.” They can also be obtained on request from IEEE or viewed at <http://standards.ieee.org/IPR/disclaimers.html>.

### **Notice and Disclaimer of Liability Concerning the Use of IEEE Standards Documents**

IEEE Standards documents (standards, recommended practices, and guides), both full-use and trial-use, are developed within IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (“IEEE-SA”) Standards Board. IEEE (“the Institute”) develops its standards through a consensus development process, approved by the American National Standards Institute (“ANSI”), which brings together volunteers representing varied viewpoints and interests to achieve the final product. IEEE Standards are documents developed through scientific, academic, and industry-based technical working groups. Volunteers in IEEE working groups are not necessarily members of the Institute and participate without compensation from IEEE. While IEEE administers the process and establishes rules to promote fairness in the consensus development process, IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards.

IEEE Standards do not guarantee or ensure safety, security, health, or environmental protection, or ensure against interference with or from other devices or networks. Implementers and users of IEEE Standards documents are responsible for determining and complying with all appropriate safety, security, environmental, health, and interference protection practices and all applicable laws and regulations.

IEEE does not warrant or represent the accuracy or content of the material contained in its standards, and expressly disclaims all warranties (express, implied and statutory) not included in this or any other document relating to the standard, including, but not limited to, the warranties of: merchantability; fitness for a particular purpose; non-infringement; and quality, accuracy, effectiveness, currency, or completeness of material. In addition, IEEE disclaims any and all conditions relating to: results; and workmanlike effort. IEEE standards documents are supplied “AS IS” and “WITH ALL FAULTS.”

Use of an IEEE standard is wholly voluntary. The existence of an IEEE standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard.

In publishing and making its standards available, IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity nor is IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing any IEEE Standards document, should rely upon his or her own independent judgment in the exercise of reasonable care in any given circumstances or, as appropriate, seek the advice of a competent professional in determining the appropriateness of a given IEEE standard.

IN NO EVENT SHALL IEEE BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO: PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE PUBLICATION, USE OF, OR RELIANCE UPON ANY STANDARD, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE AND REGARDLESS OF WHETHER SUCH DAMAGE WAS FORESEEABLE.

## Translations

The IEEE consensus development process involves the review of documents in English only. In the event that an IEEE standard is translated, only the English version published by IEEE should be considered the approved IEEE standard.

## Official statements

A statement, written or oral, that is not processed in accordance with the IEEE-SA Standards Board Operations Manual shall not be considered or inferred to be the official position of IEEE or any of its committees and shall not be considered to be, or be relied upon as, a formal position of IEEE. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that his or her views should be considered the personal views of that individual rather than the formal position of IEEE.

## Comments on standards

Comments for revision of IEEE Standards documents are welcome from any interested party, regardless of membership affiliation with IEEE. However, IEEE does not provide consulting information or advice pertaining to IEEE Standards documents. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Since IEEE standards represent a consensus of concerned interests, it is important that any responses to comments and questions also receive the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to comments or questions except in those cases where the matter has previously been addressed. For the same reason, IEEE does not respond to interpretation requests. Any person who would like to participate in revisions to an IEEE standard is welcome to join the relevant IEEE working group.

Comments on standards should be submitted to the following address:

Secretary, IEEE-SA Standards Board  
445 Hoes Lane  
Piscataway, NJ 08854 USA

## Laws and regulations

Users of IEEE Standards documents should consult all applicable laws and regulations. Compliance with the provisions of any IEEE Standards document does not imply compliance to any applicable regulatory requirements. Implementers of the standard are responsible for observing or referring to the applicable regulatory requirements. IEEE does not, by the publication of its standards, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

## Copyrights

IEEE draft and approved standards are copyrighted by IEEE under US and international copyright laws. They are made available by IEEE and are adopted for a wide variety of both public and private uses. These include both use, by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of engineering practices and methods. By making these documents available for use and adoption by public authorities and private users, IEEE does not waive any rights in copyright to the documents.

## Photocopies

Subject to payment of the appropriate fee, IEEE will grant users a limited, non-exclusive license to photocopy portions of any individual standard for company or organizational internal use or individual, non-commercial use only. To arrange for payment of licensing fees, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

## Updating of IEEE Standards documents

Users of IEEE Standards documents should be aware that these documents may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. An official IEEE document at any point in time consists of the current edition of the document together with any amendments, corrigenda, or errata then in effect.

Every IEEE standard is subjected to review at least every 10 years. When a document is more than 10 years old and has not undergone a revision process, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE standard.

In order to determine whether a given document is the current edition and whether it has been amended through the issuance of amendments, corrigenda, or errata, visit the IEEE Xplore at <http://ieeexplore.ieee.org/> or contact IEEE at the address listed previously. For more information about the IEEE-SA or IEEE's standards development process, visit the IEEE-SA Website at <http://standards.ieee.org>.

## Errata

Errata, if any, for all IEEE standards can be accessed on the IEEE-SA Website at the following URL: <http://standards.ieee.org/findstds/errata/index.html>. Users are encouraged to check this URL for errata periodically.

## Patents

Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken by the IEEE with respect to the existence or validity of any patent rights in connection therewith. If a patent holder or patent applicant has filed a statement of assurance via an Accepted Letter of Assurance, then the statement is listed on the IEEE-SA Website at <http://standards.ieee.org/about/sasb/patcom/patents.html>. Letters of Assurance may indicate whether the Submitter is willing or unwilling to grant licenses under patent rights without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination to applicants desiring to obtain such licenses.

Essential Patent Claims may exist for which a Letter of Assurance has not been received. The IEEE is not responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patents Claims, or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this standard are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility. Further information may be obtained from the IEEE Standards Association.

## Participants

At the time this IEEE recommended practice was completed, the DEI/SC/HVDC Cable Systems Working Group had the following membership:

**Giovanni Mazzanti**, *Chair*  
**Massimo Marzinotto**, *Vice Chair*

Jerome Castellon  
George Chen  
John Fothergill  
Mingli Fu

Naohiro Hozumi  
June-Ho Lee  
Jian Li  
Frank Mauseth  
Peter Morshuis

Clive Reed  
Yasuhiro Tanaka  
Antonios Tzimas  
Kai Wu

The following members of the individual balloting committee voted on this recommended practice. Balloters may have voted for approval, disapproval, or abstention.

Ettore Bartolucci  
William Byrd  
Jerome Castellon  
George Chen  
Namal Fernando  
John Fothergill  
Mingli Fu

Paul Gaberson  
Randall Groves  
Werner Hoelzl  
Alexander Kraetge  
Michael Lauxman  
Jian Li  
Arturo Maldonado  
Massimo Marzinotto

Frank Mauseth  
Giovanni Mazzanti  
Peter Morshuis  
Clive Reed  
Yasuhiro Tanaka  
Antonios Tzimas  
Kai Wu

When the IEEE-SA Standards Board approved this recommended practice on 23 March 2017, it had the following membership:

**Jean-Philippe Faure**, *Chair*  
**Vacant Position**, *Vice Chair*  
**John D. Kulick**, *Past Chair*  
**Konstantinos Karachalios**, *Secretary*

Chuck Adams  
Masayuki Ariyoshi  
Ted Burse  
Stephen Dukes  
Doug Edwards  
J. Travis Griffith  
Gary Hoffman

Michael Janezic  
Thomas Koshy  
Joseph L. Koepfinger\*  
Kevin Lu  
Daleep Mohla  
Damir Novosel  
Ronald C. Petersen  
Annette D. Reilly

Robby Robson  
Dorothy Stanley  
Adrian Stephens  
Mehmet Ulema  
Phil Wennblom  
Howard Wolfman  
Yu Yuan

\*Member Emeritus

## Introduction

This introduction is not part of IEEE Std 1732-2017, IEEE Recommended Practice for Space Charge Measurements on High-Voltage Direct-Current Extruded Cables for Rated Voltages up to 550 kV.

Recently many high-voltage direct-current (HVDC) cable systems with extruded insulation have been installed all over the world (Mazzanti and Marzinotto [B13]). Since extruded insulation for HVDC cables is strongly affected by trapped space charge, several space charge measurement methods have been developed since the mid-1980s. So far, space charge measurements have mostly been made using thin, small-size plaques and mini-cables. Much less effort has been devoted to cables of size and design comparable or equal to the full-size cables installed in the field. On the other hand, space charge measurements on full-size cables are of great interest for practical cable systems, as such measurements enable actual service conditions of power cables to be evaluated.

Inherent difficulties mainly related to thick insulation make measuring space charge on full-size cables difficult. However, since the 1990s, satisfactory space charge measurements on large HVDC extruded cables have been described in the literature. Furthermore, space charge measurements on full-size HVDC extruded cable loops have been, and are being, used worldwide in qualification tests for HVDC extruded cable link projects. These measurements are based on project-dependent agreements between cable manufacturers and the customers, as there is no agreed standard procedure.

Aiming to fill this gap, in 2015 a position paper prepared by the IEEE DEIS HVDC Cable Systems Technical Committee was published (Mazzanti, et al. [B12]). The paper illustrates a protocol for the measurement of space charge on full-size HVDC extruded cables during load cycle qualification tests (either the long-duration voltage test of prequalification tests or the load cycle test of type tests). The protocol incorporates experience gained in the above-mentioned space charge measurements for HVDC extruded cable system projects.

This recommended practice aims at improving this protocol and establishing it as a reference IEEE best practice for the measurement of space charge on full-size HVDC extruded cables. At the time of writing of this document, the maximum rated voltage of HVDC extruded cable systems commissioned worldwide is 320 kV, but systems with rated voltage up to 525 kV are being qualified. Moreover, in 2012 CIGRÉ issued the Technical Brochure 496 entitled “Recommendations for Testing DC Extruded Cable Systems for Power Transmission at a Rated Voltage up to 500 kV” (see [Clause 2](#)). Aiming at accounting for these recent and/or ongoing developments, an upper limit of 550 kV has been selected for the rated voltage of HVDC extruded cables to which the present recommended practice is applicable.

## Contents

1. Overview .....	9
1.1 Scope .....	9
2. Normative references .....	9
3. Definitions, acronyms, and abbreviations .....	10
3.1 Definitions .....	10
3.2 Acronyms and abbreviations .....	11
4. Recommended space charge measurement methods .....	12
5. Space charge measurements during the prequalification test .....	12
5.1 Introduction .....	12
5.2 Measurements by means of the PEA method .....	12
5.3 Measurements by means of the TSM .....	18
6. Space charge measurements during the type tests .....	22
6.1 Measurements by means of the PEA method .....	22
6.2 Measurements by means of the TSM .....	24
Annex A (informative) The PEA method for space charge measurements on cables .....	26
Annex B (informative) The TSM for space charge measurements in cables .....	29
Annex C (informative) Calibration .....	31
Annex D (informative) Bibliography .....	33

# IEEE Recommended Practice for Space Charge Measurements on High-Voltage Direct-Current Extruded Cables for Rated Voltages up to 550 kV

## 1. Overview

### 1.1 Scope

This standard recommends best practices for the measurement of space charge on high-voltage direct-current (HVDC) extruded cables having rated voltage up to 550 kV. Focus is on poling time, depolarization time, heating and cooling of specimens. Particular reference is made to space charge measurements to be carried out during load cycle qualification tests (either prequalification or type test load cycles). The ultimate goal of this standard is not checking the compliance with any maximum acceptable limit of either space charge or electric field; rather, assessing the variation of the electric field profile in the cable insulation wall during load cycle qualification tests.

## 2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

CIGRÉ Technical Brochure 288:2006, Guide for Space Charge Measurement in Dielectrics and Insulating Materials—PEA, PWP (PIPWP & LIPP) and TSM Methods.

CIGRÉ Technical Brochure 496:2012, Recommendations for Testing DC Extruded Cable Systems for Power Transmission at a Rated Voltage up to 500 kV.

IEC 60060-1:2010, High-Voltage Test Techniques—Part 1: General Definitions and Test Requirements.<sup>1</sup>

---

<sup>1</sup>IEC publications are available from the International Electrotechnical Commission (<http://www.iec.ch/>). IEC publications are also available in the United States from the American National Standards Institute (<http://www.ansi.org/>).